METHOD AND SYSTEM FOR PERFORMING DIGITAL BEAM FORMING AT INTERMEDIATE FREQUENCY ON THE RADIATION PATTERN OF AN ARRAY ANTENNA

5   DESCRIPTION

Field of the invention

The present invention refers to a method and a system for controlling the radiation pattern of an array antenna at intermediate frequency (IF) through digital processing.

10   Array antennas are very attractive solutions whenever beamshaping capability is needed. The beamshape control in array antennas can be accomplished with by manipulating signals at different stages of the transceiver chain.

Even if array antennas have many fields of 15 application, mobile communications are preferred, but not exclusive, ones. In fact, in a mobile communication system the capability of adjusting cell borders and size is certainly a major key factor, especially if it can be performed remotely from a centralised location. As an 20 example, it allows to efficiently cope with traffic spatial distribution periodicity in time, that is typical in urban areas, as well as with the cell breathing effect of CDMA-based networks).

Background art

25   Nowadays cell size adjustment can be obtained by typically changing the beam tilt of the antenna through electro-mechanical actuators that control passive devices performing analogue Radio Frequency (RF) processing. This solution, however, presents many drawbacks, as its beam-30 shaping capability is poorly versatile.

2

In order to overcome the limitations of the previous approach, digital beamforming techniques can be applied.

According to classical electromagnetic theory, the shape of the beam radiated by planar or linear array antenna can be written as

$$\underline{E}(\underline{r}) = \underline{E}_0(\underline{r})F(\hat{r})$$

where $\underline{E}_0(\underline{r})$ is the electromagnetic field radiated by each antenna element, $\underline{r}$ is the spatial vector, $\hat{r}$ is the unity-module vector with direction corresponding to spatial vector $\underline{r}$ and $F(\hat{r})$ is the array factor of the antenna. Once the basic radiating element is chosen ($\underline{E}_0(\underline{r})$), the shape of the radiation pattern can be fully controlled by operating on the array factor only.

For a Uniform Linear Array (ULA), composed by equally spaced elements, the array factor has the following expression:

$$F(\alpha) = \sum_{n=0}^{N-1} w_n \, \exp[jk_0 nd \cos(\alpha)]$$

where $k_0 = 2\pi/\lambda$ is the wave number, λ is the wavelength, d is the inter-element spacing, α is the observation direction and $w_n = w_{rn} + jw_{in} = |w_n| \exp(j\angle w_n)$, which is the n-th feed coefficient or weight of the array, allows full control over the array factor shape (hence the beam shape of the field radiated by the antenna).

Techniques devoted to implementing beam forming can be classified into two main approaches: radio frequency (RF) processing and base band (BB) processing.

If radio frequency (RF), typically analogue, processing is considered, weights are applied through RF components which are able to modify both amplitude (RF amplifiers) and phase (RF phase shifters) of RF signal to/from each radiating element.

Document WO 03/015212 illustrates an active phased array antenna system in which a beam former is operable to process an analogue radio frequency signal or an analogue intermediate frequency signal. Programmable electronic power splitters and phase shifters, operating on analogue signals, are used for controlling both the amplitude and phase of each element of the antenna. Phase shifter in particular, which are implemented as Butler matrices, are quite complex systems, whose realization and integration into base stations or transceiver terminals can be complicated.

On the other hand, if baseband (BB), typically digital, signal processing is considered, beam forming is usually realized by multiplying digitised base-band complex signals at each array element by suitable complex coefficients (both in up-link and down-link). An example of a prior art digital beam forming baseband processing (down-link) is shown in Figure 1.

In down-link, if a generic n-th array element is considered, the complex envelope signal related to it is

$$s_{BBn}^{w} = w_n \, \widetilde{s}(t)$$

where $\widetilde{s}(t) = i(t) + jq(t)$ is the complex envelope of the input signal.

Hence, with reference to the scheme of Figure 1, base-band digital processing just operates a multiplication 2 of

4

a complex input signal $\tilde{s}(t)$ by a complex coefficient w_n. Once the signal input to the antenna has been weighted, it follows the standard steps through the down-link radio chain: up-conversion 6 to radio frequency (RF), through an intermediate frequency (IF) conversion 4, and high power amplification, not shown in Figure 1.

The block diagram in Figure 1 is also valid for the so-called zero-IF technique where the baseband signal is directly up-converted to RF (f_0), assuming that $f_{IF} = f_0$ and $f_\Delta = 0$.

Digital beam forming techniques applied to base-band signals are illustrated for example in documents US 6,052,085 and US 2002/154687.

The techniques illustrated in the above-mentioned documents, operating on baseband signals, imply a good knowledge of how data corresponding to the base-band signals are organized and dealt with in the processing chain. In fact, usually, and particularly with regard to telecommunication apparatuses, this is a confidential and restricted information of the manufacturer. Moreover, if a remote control has to be implemented, apparatuses of the same manufacturer must be necessarily used.

The Applicant has tackled the problem of efficiently performing beam shaping on the radiation pattern of an array antenna, operating exclusively on digital signals.

The Applicant observes that digital beam-forming techniques are much more efficient and cost-effective than analogue ones.

In view of the above, it is an object of the invention to provide an efficient beam shaping technique which can be applied to digitised intermediate frequency signals.

Summary of the invention

The object of the present invention is thus to provide an arrangement that overcomes the drawbacks of the prior
5   art arrangements as outlined in the foregoing.

According to the present invention, that object is achieved by means of a method and a system having the features set forth in the claims that follow.

10   The present invention also relates to a corresponding base transceiver station, incorporating the system of the invention, and a computer program product loadable in the memory of at least one computer and including software code portions for performing the method of the invention.

15   The Applicant has found that beam forming can be obtained by processing a digital intermediate frequency signal, by taking advantage of all capabilities of digital signal processing applied to antenna arrays, so that the resulting beam shape can be the same as the one obtained
20   through more common either base-band or radio-frequency signal processing.

The Applicant has verified that weighting coefficients can be applied to an intermediate frequency signal, provided that the same signal has been previously
25   duplicated in two identical components, the first component being subjected to a Hilbert transform operation and the second component being delayed in order to maintain it temporarily aligned with the first one.

While digital beam-forming is usually performed on
30   base-band signals, which manufacturers typically do not allow to access for confidentiality reasons, the invention manages intermediate frequency signals only, according to

an OEM-independent and non-intrusive approach. The choice of intermediate frequency signals can be considered a manufacturer-independent one, enabling the present approach

5   to be applied to every kind of beam forming systems where the intermediate frequency stage is implemented.

Brief description of the drawings

Figure 1 is an exemplary schematic diagram of a prior

10 art digital beam forming baseband processing system;

Figure 2 is a first exemplary schematic diagram of a digital beam forming processing system realised according to the present invention;

Figure 3 is a second exemplary schematic diagram of a

15 digital beam forming processing system realised according to the present invention;

Figure 4 is a functional block diagram of a portion of a signal processing chain in a base transceiver station realised according to the present invention;

20 Figure 5 is a block diagram of a digital beam forming processing system in a downlink stage of a base transceiver station realised according to the present invention;

Figure 6 is a block diagram of a digital beam forming processing system in an uplink stage of a base transceiver

25 station realised according to the present invention;

Figure 7 is a first exemplary block diagram of a base transceiver station incorporating a digital beam forming processing system realised according to the present invention;

30 Figure 8 is a second exemplary block diagram of a base transceiver station incorporating a digital beam forming

processing system realised according to the present invention; and

Figure 9 is a third exemplary block diagram of a base transceiver station incorporating a digital beam forming processing system realised according to the present invention.

Detailed description of the preferred embodiments

A first exemplary schematic diagram of a digital beam forming processing system realised according to the present invention is shown in Figure 2. An intermediate frequency IF signal S_{IF}, obtained for example by up-conversion 12 from a base band input signal $\tilde{s}(t) = i(t) + jq(t)$, is processed by a beam forming block 10a, for obtaining an output weighted IF signal S_{IF}^W. The output signal S_{IF}^W is then up-converted 19 to a radio frequency signal S_{RF}, according to well known techniques.

The operation of beam forming block 10a will now be explained in detail. The S_{IF}^W signal, centred at frequency f_{IF}, feeding the n-th antenna element of an array antenna, can be expressed as

$$s_{IFn}^w(t) = \text{Re}\{w_n \tilde{s}(t) \exp(j2\pi f_{IF}t)\}$$

where W_n is the n-th complex weight and $\tilde{s}(t) = i(t) + jq(t)$ is the complex envelope of the IF signal. The previous equation can be rewritten as:

$$\begin{aligned} s_{IFn}^w(t) &= w_{rn} \text{Re}\{\tilde{s}(t)\exp(j2\pi f_{IF}t)\} + w_{in} \text{Re}\{\tilde{s}(t)\exp(j2\pi f_{IF}t + \pi/2)\} \\ &= w_{rn} \text{Re}\{\tilde{s}(t)\exp(j2\pi f_{IF}t)\} - w_{in} \text{Im}\{\tilde{s}(t)\exp(j2\pi f_{IF}t)\} \end{aligned}$$

where the non-weighted IF signal and its Hilbert transform are multiplied by the real and the imaginary part

of W_n respectively. Hence, the weighted IF signal can be expressed as:

$$s_{IFn}^{w}(t) = w_{rn}\, s_{IF}(t) - w_{in}\, \mathrm{H}\{s_{IF}(t)\}$$

5   where

$$s_{IF}(t) = \mathrm{Re}\{\widetilde{s}(t)\, \exp(j2\pi f_{IF}t)\}$$

is the non-weighted real IF signal and $\mathrm{H}\{\cdot\}$ is the Hilbert transform operator.

With reference to Figure 2, the S_{IF} signal is
10 duplicated and processed in parallel by two signal processing sub-chains. A Hilbert transform block 16 operates a Hilbert transform on the S_{IF} signal, afterwards the transformed signal is multiplied, in block 17, by an imaginary part W_i of the complex weight coefficient. In a
15 second signal processing sub-chain the S_{IF} signal is delayed by a predetermined time, block 14, in order to maintain such signal temporarily aligned with the corresponding transformed signal, and then multiplied, in block 15, by a real part W_r of the complex weight
20 coefficient.

The two signals are then combined, by means of a subtracter 18, into a weighted digital IF signal S_{IF}^{W}, by subtracting the signal which has been multiplied by the imaginary part W_i of the complex weight coefficient from
25 the signal which has been multiplied by the real part W_r of the same weight coefficient.

Thanks to the linearity property of the Hilbert transform, an alternative embodiment 10b of the beam forming block 10a previously illustrated can be derived as
30 shown in Figure 3, where: the duplicated S_{IF} signals are first multiplied by the real W_r and imaginary part W_i of

the complex weight coefficient, in blocks 15 and 17
respctively; then the signal output by block 15 is delayed
14, while the signal output by block 17 is Hilbert-
transformed 16; a subtracter 18 combines the two signals,
as previously described with reference to Figure 2, into a
weighted digital IF signal S_{IF}^{W}.

Either block 10a or block 10b can be used for
transforming the input signal S_{IF} into its weighted version
S_{IF}^{W}. For optimization purposes, block 10a can be used in a
down-link signal processing stage of a base station, while
block 10b can be used in an up-link signal processing stage
of a base station. In that way, in fact, the architecture
of a base station transceiver can be significantly
simplified by using one Hilbert transformer per stage only.

The weight coefficients used in blocks 10a and 10b,
operating at IF, can be the same weight coefficients which
are used for base-band or radio frequency processing, in
prior art arrangements.

Figure 4 shows a functional block diagram of a portion
of a signal processing chain in a base transceiver station.
A down-link beam forming module 30, operating according to
the method previously illustrated, transforms an IF signal
S_{IF}, into a plurality of weighted IF signals $S_{IF}^{W1}..S_{IF}^{WN}$ and
operates on the weighted signals an up conversion to
corresponding RF signals $S_{RF}^{1}..S_{RF}^{N}$, as explained in detail
hereinbelow with reference to Figure 5.

Radio frequency signals $S_{RF}^{1}..S_{RF}^{N}$ are then processed by
blocks 32a..32c, in which they are filtered 36 in order to
erase spurious components, and then amplified 38, just
before reaching a duplexer 40 and a corresponding antenna
element 34a..34c. The duplexer allows to use the same
antenna for both up and down-link.

In up-link the signal received, through duplexer 40, from each antenna element 34a..34c is filtered 42 in order to reduce noise effects and then amplified 44, before

5   reaching an up-link beam forming module 50, explained in detail hereinbelow with reference to Figure 6.

With reference to Figure 5, the IF signal S_{IF} is splitted into two identical signals, a first one is delayed in block 62 to be temporarily aligned to the second one,

10   which is processed by a Hilbert transformer 64, for example a digital filter specifically designed. The two signals, respectively S_{IF} and H_{IF}, are then replicated N times by means of a splitter 66. Then each replica of the couple S_{IF}, H_{IF} is multiplied by the real and the imaginary part of the

15   corresponding weight. They are then subtracted in block 70a..70n, obtaining weighted signals $S_{IF}^{W1}..S_{IF}^{WN}$, and converted to analogue signals by means of a D/A converter. A final up-conversion through blocks 69a..69n, is required to get the output RF signals $S_{RF}^{1}..S_{RF}^{N}$.

20   With reference to Figure 6, the RF signals $S_{RF}^{1}..S_{RF}^{N}$, received from blocks 32a..32c in Figure 4, are down converted to IF, in blocks 79a..79n, and the resulting signals are digitised, by means of A/D converters 77a..77n, and splitted into two replicas. Each replica of signal

25   couple is subject to a weighting operation 75a..75n, and the contribution from all N branches 78a..78n are summed by means of a first 76 and a second 77 adder before reaching a common Hilbert transform block 74 and a common delay block 72. The two signals are then subtracted, block 80,

30   obtaining a weighted IF signal S_{IF}^{W}.

Figures 7, 8 and 9 show three exemplary block diagrams of base transceiver stations (BTS) incorporating a system for performing digital beam forming on the radiation

pattern of an array antenna realised according to the invention. A base transceiver stations BTS schematically comprises a central unit 90, coupled to a core network by means of a link 95, and an antenna unit 93, connected to the central unit 90 by means of a link 97, e.g. a cable (either electric, such as coaxial cable, or optical, such as optical fibre cable) or a plurality of cables. The base station comprises a base band processing module 92, a first conversion module 94 (BB <-> IF) for converting BB signals to IF signals and vice-versa, a beam forming module 96 operating on IF signals according to the present invention, a second conversion module 98 (IF <-> RF) for converting IF signals to RF signals and vice-versa, and a plurality of antenna elements 100.

In the exemplary block diagram of Figure 7 the beam forming module 96 is incorporated into the antenna unit 93, which receives an IF signal from the central unit 90 through the link 97.

In the exemplary block diagram of Figure 8 the central unit 90 comprises the beam forming module 96, which is connected to the second conversion module 98 (IF <-> RF) by means of a plurality of links 1..N, one for each antenna element 100.

In the third exemplary block diagram, shown in Figure 9, both the beam forming module 96 and the second conversion module 98 (IF <-> RF) are incorporated into the central unit 90, which is connected to the antenna unit 100 by means of a plurality of links 1..N, one for each antenna element 100.